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I also certify that the application is now proceeding in the name as identified herein.

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Dated 7 December 2004

GB0327041.0

By virtue of a direction given under Section 30 of the Patents Act 1977, the application is proceeding in the name of

BAE SYSTEMS PLC,
Incorporated in the United Kingdom,
6 Carlton Gardens,
LONDON,
SW1Y 5AD,
United Kingdom

[ADP No. 07914674004]

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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

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1. Your reference

2003P17754 GB / R76 / MOM / JBO

2. Patent application number
(The Patent Office will fill in this part)

0327041.0 21 NOV 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Roke Manor Research Limited
Roke Manor,
Old Salisbury Lane
Romsey,
Hampshire SO51 0ZN

(1977 ACT) APPLICATION FILED 3/9/04

Patents ADP number *(if you know it)*

05615455007

If the applicant is a corporate body, give the country/state of its incorporation

UNITED KINGDOM

4. Title of the invention

5. Name of your agent *(if you have one)*

BAE Systems plc, Group IP Dept.

"Address for service" in the United Kingdom to which all correspondence should be sent
(including the postcode)

Lancaster House
P.O. box 87
Farnborough Aerospace Centre
Farnborough
Hampshire
GU14 6YU.

~~Siemens Shared Services~~
~~Intellectual Property Department~~
~~Siemens House~~
~~Oldbury, Bracknell, Berkshire RG12 8FZ~~

Patents ADP number *(if you know it)*

07914674002.

~~85827769001~~

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute *(see note f)*.

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8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request? — Yes

Answer YES if:
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
Otherwise, answer NO (see note d).

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form.

Continuation sheets of this form	
Description	11 ✓ CF
Claim*(s)*	0
Abstract	0
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10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translation of priority documents	
Statement of inventorship and right to grant a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application

Signature Date

Marc Morgan 20.11.2003
Intellectual Property Department

12. Name and daytime telephone number of Person to contact in the United Kingdom — Marc Morgan + 44 1980 86 3813

IDNR: 7100 / V: 03-1.01 / B: Val

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Apparatus and Methods

The inventions relate in, the specific embodiment,t to apparatus and methods for use in an object location and or tracking system. The described system is one proposed under the trademark CELLDAR™ but the inventions have a wider applicability including electronic apparatus in general.

CELLDAR utilises radio-waves emanating from base-stations in a cellular communication system to locate objects. A first invention comprises a novel technique, whereby the reference signal required by the CELLDAR™ radar receiver may be recovered & regenerated with high accuracy. CELLDAR™ obtains target information by correlating the reference signal from the transmitter with reflected signals in both the time and frequency domains. An approximation to the reference signal may easily be obtained by use of a high gain antenna directed towards the base station feeding a second receiver channel, which is phase locked to the target detection receiver. However, the reference so obtained is generally corrupted by multipath and interference from other distant base stations re-using the same frequency. These effects limit the dynamic range of breakthrough cancellation.

In the first invention, the phase & frequency of the reference signal with respect to the receiver local oscillator are recovered and the channel impulse response is estimated. This information is used to correct the received signal for phase & frequency offsets and multipath delays and then to demodulate

the symbol stream in the signal. The demodulated symbols are hard limited, which has the effect of removing any interference, provided that the wanted signal is significantly larger than the interference, which is the case of interest. The appropriate modulation is then applied to the recovered symbols and the previously measured phase & frequency offsets are incorporated, to create a regenerated reference signal uncorrupted by multipath or interference.

The following description of the technique is given in terms of its current implementation, using GSM signals, but the technique can be applied to any digital cellular radio system whose signal structure contains defined synchronisation bursts, training sequences, preambles etc., without loss of generality. Thus the invention is not limited to the CELLDAR system.

In GSM systems, initial frame and burst timing is obtained by a correlation search for the main synchronisation bursts, and the timing, phase & frequency offset information is then obtained by correlating the centre section of selected GSM bursts with stored versions of the allowed modulation patterns for those bursts. Conventional GSM receivers decode information from the signal to establish which bursts contain data relevant to them, and which of the set of 8 training sequences is being used to characterise those bursts. Bursts containing no data are filled with a "dummy" code and are not processed. However, the CELLDAR™ receiver must demodulate the entire signal, so that it performs a maximum likelihood correlation for all the training sequences, treating the dummy burst as an extra training sequence. Since each correlation is performed over a span of

symbols (16 or more) significant processing gain is achieved against any interference.

The magnitudes and positions of the complex correlation peaks are also used to maintain signal timing and to identify which GSM burst timing option is in use (e.g. many transmitters use a burst length cycle of 156, 156, 156, 157 etc. symbols instead of the nominal 156.25 symbol burst length defined in the ETSI specifications). Such timing differences are irrelevant to normal GSM receivers, but CELLDAR™ must identify the option in use, as it must recover the entire signal. The ratios of the real & imaginary correlation results are used to determine the phase & frequency offset data.

Control bursts, whose positions are known from the signal structure, such as frequency correction bursts & synchronisation bursts, are processed appropriately to recover the required data.

A further feature of the invention, is that the close-in phase noise of the down-converted reference is automatically recovered and re-applied to the regenerated signal. The regenerated reference must contain this phase noise, in order to cancel the identical phase noise present on breakthrough & clutter in the target detection process. The GSM burst rate is approximately 1.73 kHz, which represents the Nyquist rate for phase noise sampling, and implies phase noise cancellation below target Doppler frequencies of 866 Hz. The Doppler frequencies of most targets of interest are significantly lower than this.

In situations where the breakthrough from the transmitter into the target detection channel of the receiver is sufficiently large, the technique may be applied to this breakthrough signal itself, thus obviating the need for a separate reference receiver & antenna.

A second invention comprises a novel technique for the calibration of phased array antenna systems used by the CELLDAR™ radar receiver, and exploits the properties of the cellular radio signals which CELLDAR™ uses operationally. The description is given in terms of GSM modulation, but the technique can be applied to any digital cellular radio system without loss of generality.

In order to optimise performance and increase flexibility, CELLDAR™ is being designed to use a phased array antenna system for synthetic beam/null generation and steering. Such arrays comprise a number of antennas, with parallel receiver channels, cabling, A/D converters and digital IF systems. The outputs of these parallel channels are suitably combined in amplitude & phase to create the desired antenna beam patterns. This process can only be performed successfully if the transfer characteristics of each of the channels are known.

These characteristics are generally determined by injecting a known signal into each of the receiver channels and measuring the IF outputs. Normally a simple sinusoid is used, but with this invention a special GSM-like signal is employed. This signal is generated by selecting a pseudo-random binary sequence which has good auto-correlation properties. GMSK modulation is

applied and the result is up-converted to the calibration channel frequency. Appropriate signals may be easily generated by test equipment.

Calibration is achieved by performing a complex correlation of the signal from each receiver channel with the original GMSK-modulated pseudo-random sequence. The correlation result has the following important properties.

1. Since the correlation can be performed over a wide symbol span, there is obtained considerable processing gain against noise, thus enhancing the accuracy of the calibration.

2. The calibration signal has the same spectral & modulation characteristics as a normal GSM signal, so that the effects of filter characteristics, amplifier group delays etc. will be accurately reproduced in the calibration.

3. The amplitude and phase characteristics of each channel are simply obtained from the real & imaginary results of the complex correlations.

4. The position of the correlation peak permits the delay through each channel to be measured. This may be important when digital receiver techniques are employed, since the latency through DSP chips may be significant and may in addition be different at each power up. This can occur, for example, if the DSP or interface clocks are derived from dividing down a high frequency master clock by 4,

so that each logic block in the system then has the choice of selecting at random from one of 4 clock phases at power up.

Although the invention is described in terms of an optimised GSM-like signal generated by the CELLDAR™ equipment, the scope does not exclude the use of a signal received directly by the antennas from a local base station. In this case, the calibration would either be performed by cross-correlation between the channels or with a reference obtained from a second receiver and antenna, optimised to receive the base station signal.

The CELLDAR™ radar receiver obtains target information (range and velocity) by comparing the reference signal direct from the transmitter with reflected signals, utilising both the time and frequency domains. In addition to returns from genuine targets, large interfering signals are generally also present, and these create noise and spurii in the comparison process in a number of complex ways, which have the result of desensitising the detection performance of the system.

Interference can be caused by breakthrough of the reference signal via the target antenna sidelobes and through reflections from ground clutter.

The method of reducing the effect of this type of interference described here depends on the fact that the CELLDAR™ system can categorise all received signals in terms of delay, Doppler frequency and phase relative to the reference signal, and also that the principal sources of interference have much smaller delays and Doppler frequencies than the target classes of interest.

A third invention provides a back off method in which the received signal is first of all processed by correlation against the reference to extract the signal returns present in the set of range-Doppler cells identified as covering the significant interferers. These returns are then used to estimate the amplitudes and phases of such interferers relative to the reference signal.

Finally, equal and opposite polarity signals to these interferers are generated using the stored reference signal and these signals are added to the raw received signal in order to cancel out the interferers.

As this system does not employ feedback, in principle no residual interference "error" term is involved, so the cancellation depth is limited only by the precision to which the parameters of the interfering signals can be measured and then reconstructed.

Increased performance can be obtained if the process is applied iteratively.

The proposed CELLDAR™ system applies this technique to GSM signals, but it can be adapted to any digital cellular radio system without loss of generality.

In the broadest sense, the forth invention measures interference during the period of time allocated to a predetermined signalling signal. A forth invention applicable to a cellular communications system and in particular a GSM communications system permits the measurement of the level of interference due to frequency re-use in adjacent cells. Normally it is difficult

to measure such interference, since although it may be significant in system terms, it may be 30 dB or more below the level of the wanted signal. Limited measurement may be possible during the guard periods of the wanted transmission, but these periods are of such short duration that power assessment is difficult, they may be compromised by the response time of the receiver, and also because the wanted transmitter may not reduce its power significantly during the guard periods.

A novel method is proposed, which exploits the pre-defined modulation characteristics of certain elements of the GSM signal. For illustrative purposes, the use of the Frequency Correction Burst (FCB) is described here, but this does not exclude the use of other elements of the signal, or extension of the method to other digital cellular radio systems.

FCBs occur on a regular basis in the BCCH channel and each is of significant length (142 symbols) with a specified modulation pattern, thus giving known periods of a received signal with defined properties from the wanted transmitter, during which signal power measurement can be performed. The receiver synchronises to the BCCH signal in the normal way, using the synchronisation bursts, and then locates the positions of the FCBs. Each received FCB is filtered with an FIR whose weights are the complex conjugate of the FCB signal modulation applied at the transmitter. The output from the filter is then analysed statistically. If no interference is present, the output will have a constant value, which is proportional to the power of the wanted received signal. If interference is present, the output will have in addition a noise-like component superimposed, generated by the

convolution of the FCB filter weights with the essentially independent pseudo-random modulation of the interfering signal.

By measurement of the mean & variance of the filter output over a received signal span which includes several FCBs and applying a suitable averaging, the signal to interference ratio can then be estimated to a high degree of accuracy over a wide dynamic range.

The results can be used simply to measure the interference levels for survey purposes, or can provide a control signal for advanced system functions such a steering of an antenna null towards the interfering transmission.

A fifth invention can reduce substantially the level of spurii in the spectrum of an unknown signal which is corrupted by bursts of regular or quasi-regular interference, the timing characteristics of which are known. Whilst described in terms of the CELLDAR system it is not limited to such a system.

It can be shown mathematically that the effect of interference bursts cannot be removed entirely unless each burst can be substituted by an accurate estimate of the original signal waveform over each burst period. It may be possible to perform such a substitution to an acceptable degree of precision when the signal is strong and not corrupted by noise, but in the case where the wanted signal is weak and not visible above the level of noise and other unwanted signals, substitution cannot be successfully performed. It should also be noted that simple excision of the interference bursts is ineffective, since it merely replaces one interfering signal with another.

This process attenuates the effect of the interference bursts by typically applying a sinusoidal amplitude window to the signal, such that the zero crossing points of the sinusoid coincide with the centres of the interference bursts. For regular interference, the sinusoid has a frequency which is half that of the interference repetition rate. For quasi-regular interference, each half-period of the windowing function is adjusted to maintain the zero crossings at the burst interference midpoints.

Although the process is described here in terms of a sinusoidal windowing function with zero crossings at the interference midpoints, it does not exclude the use of other windowing functions which may be selected to achieve optimum results, taking the characteristics of the interference into account.

One result of the windowing is to selectively reduce the power of the interference relative to the wanted signal. Another result of the windowing is to apply a modulation to the wanted signal. In the spectral domain, this is observed as a splitting of each signal peak into two peaks, separated by twice the windowing frequency and centred on the true frequency. For many applications, this may be acceptable, but a good estimate of the true signal spectrum may be obtained by a simple algorithm which combines peak pairs, given the knowledge that the frequency separation is defined and the amplitudes of each peak are identical.

In the present context, this process is applied to reduce the effect of frequency correction bursts in GSM transmissions used by the CELLDAR™

passive radar system but it could be utilised in other systems where the effect of particular signalling bursts need to be alleviated.

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Bae Systems
Laura Francis

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